Published in final edited form as:
Clin Linguist Phon. 2010 February ; 24(2): 122–140. doi:10.3109/02699200903440975.

Phonological learning and lexicality of treated stimuli

Judith A. Gierut and **Michele L. Morrisette**
Indiana University, Bloomington, IN, USA

Abstract

The purpose was to evaluate the lexicality of treated stimuli relative to phonological learning by preschool children with functional phonological disorders. Four children were paired in a single-subject alternating treatments design that was overlaid on a multiple baseline across subjects design. Within each pair, one child was taught one sound in real words and a second sound in non-words; for the other child of the pair, lexicality was reversed and counterbalanced. The dependent variable was production accuracy of the treated sounds as measured during the session-by-session course of instruction. Results indicated that production accuracy of the treated sound was as good as or better using non-word as opposed to real word stimuli. The clinical implications are considered, along with potential accounts of the patterns of learning.

Keywords

phonological disorders; phonological treatment; non-words; lexicon

Introduction

There has long been an interest in understanding how the words of language may influence children's productive phonological development. In his seminal volume, Jakobson (1941/1968: 27; see also Bybee, 2001) suggested that the emergence of phonology is 'inseparably linked to the sign nature of language', such that speech sounds were thought to be a byproduct of the acquisition of words as meaningful linguistic units. As children are exposed to new words, they are apparently first drawn to their semantic properties, and only later sort out that their associated labels are comprised of unique sounds. For example, upon first encounter with a cat, a child might attend to its shape, size, colour, or action, learning that this particular animal is called 'cat'. Only later does that child come to understand that the word 'cat' consists of the unique set of sounds [k], [æ], [t]. Ferguson and Farwell (1975: 437) likewise advocate for the 'primacy of lexical items in phonological development', whereby lexical learning presumably acts as the mechanism that drives the acquisition of phonemic distinctions (see also Stoel-Gammon, 1998). By this, it is again the meaning of new words that first matters to children, with sound contrasts emerging subsequently and upon confrontation with minimal pairs (see Maye and Gerken, 2000 for an opposing view). Continuing the above example, the sounds that comprise 'cat' eventually take on phonemic status following a child's acquisition of the semantic properties of other new, but phonologically similar forms such as 'hat' or 'sat'. Notice that these views suggest that new words and their new meanings provide the bootstrap to the phonological system. An

Correspondence: Judith A. Gierut, Department of Speech and Hearing Sciences, 200 South Jordan Avenue, Indiana University, Bloomington, IN 47405-7002, USA. Tel: 812-855-9173. Fax: 812-855-5561. gierut@indiana.edu.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

implication is that the relationship between word learning and phonological learning may be unidirectional, such that from words come phones and phonemes.

More recently, the link between novel word learning and phonological development has been modelled as a bi-level and bidirectional process (Storkel and Morrisette, 2002, following Vitevitch and Luce, 1998; 1999 for fully developed language). Word learning seems to be affected at a *lexical level* by the basic characteristics of words, such as their frequency of occurrence in the language (Goodman, Dale, and Li, 2008) or their neighbourhood density (Charles-Luce and Luce, 1990; Storkel, 2004a). *Neighbourhood density*, as defined by Luce (1986), describes the overall similarity of words based on 1-phoneme substitutions, deletions or additions; e.g. 'bat, at, capped' are all neighbuors of the word 'cat'. Word learning is also affected at a *sub-lexical level* by the internal phonological form of words (Jusczyk, Luce, and Charles-Luce, 1994; Storkel, 2001; 2003), also known as *probabilistic phonotactics* (Vitevitch and Luce, 1999). Probabilistic phonotactics describe the likelihood of occurrence of sounds and sound sequences and are operationalized in terms of positional segment frequency and/or biphone frequency. *Positional segment frequency* is the likelihood of occurrence of a given sound in a given word position relative to all other permissible sounds that occur in that same position, whereas *biphone frequency* is the likelihood of co-occurring pairs of sounds relative to all other permissible co-occurrences. Aside from the effects of probabilistic phonotactic variables, additional work has shown that the composition of children's phonological inventories bears on the types of words that will be learned, and, further, this seems to vary developmentally. In early phases of word learning, there is rapid acquisition of words that consist of sounds that are present in children's inventories (e.g. Ferguson and Farwell, 1975; Schwartz and Leonard, 1982; Stoel-Gammon and Cooper, 1984). The pattern reverses in later phases of word learning, with rapid acquisition of forms that are comprised of sounds absent from children's inventories (Storkel, 2006). Thus, on probabilistic, descriptive, and experimental grounds, the attributes of novel words, together with their corresponding sounds both affect lexical learning. Importantly, and of central interest to the present study, the same appears to be true for phonological learning. Phonological learning is likewise influenced at two levels, with properties of words (Leonard and Ritterman, 1971; Beckman and Edwards, 2000b; Morrisette and Gierut, 2002; Munson and Solomon, 2004) and sounds (Munson, 2001; Edwards, Beckman, and Munson, 2004; Zamuner, Gerken, and Hammond, 2004; Cholin, Levelt, and Schiller, 2005; Munson, Kurtz, and Windsor, 2005) both contributing to the development of children's productive phonology. When taken together, it appears that words and sounds mutually support lexical, as well as phonological learning. That is, the acquisition of new words helps children acquire the sound system, but also the acquisition of new sounds (as an independent and separate process) helps children acquire words.

The apparent interaction between phonology and the lexicon takes on added significance when extended to clinical populations, including children with functional phonological disorders (Storkel and Morrisette, 2002). This sub-group of children presents with a severely reduced consonantal inventory relative to the ambient phonology, which renders their speech unintelligible. When assessed using conventional linguistic analyses (Chomsky and Halle, 1968; Dinnsen, 1984), children's unintelligibility may be traced, for the most part, to phonotactic constraints on the articulatory (i.e. phonetic; Dinnsen, Chin, Elbert, and Powell, 1990) and contrastive (i.e. phonemic; Gierut, Simmerman, and Neumann, 1994) use of sounds of the target language.[1] Their unintelligibility warrants clinical treatment, which may be designed as an experimental manipulation, with treatment serving as the independent variable and phonological learning as the dependent variable. This tack has benefitted evidence-based practice for children with phonological disorders by identifying a host of clinical, linguistic, and psycholinguistic variables that impact the *effectiveness* of phonological treatment, the *effects* of such treatment on accuracy of production of treated and/or untreated sounds, and the *efficiency* of that treatment in prompting learning (Olswang, 1998). It is from this vantage that a better understanding of the potential developmental interactions between words and sounds takes on practical relevance.

Specifically, it may be possible to capitalize on the benefits that accrue from certain types of words and sounds in the programmatic administration of clinical treatment. For obvious reasons, much thought has been given to the kinds of sounds that are treated in the course of phonological treatment (e.g. McReynolds and Bennett, 1972; Elbert and McReynolds, 1975; Shriberg, 1980; Powell and Elbert, 1984; Gierut, Morrisette, Hughes, and Rowland, 1996). There has been less attention paid to the words that are used as stimuli (Leonard and Ritterman, 1971; Gierut, Morrisette, and Champion, 1999; Morrisette and Gierut, 2002). Of the work that is available, the focus has largely been on the lexical attributes of words, such as their frequency or neighbourhood density. Yet, the related, and perhaps more basic question of whether there is a difference between RWs vs NWs for purposes of phonological learning has not yet been addressed. That is, does the lexicality of treated stimuli differentially affect children’s phonological learning in clinical treatment? This study considers this question by documenting children’s longitudinal phonological learning session-by-session following exposure to real words (RWs) vs non-words (NWs) as stimuli in treatment.

The motivation for examining lexicality in phonological treatment further follows from four sources. A first relates to the developmental proposals cited above, which implied that novel words and their newly learned meanings might facilitate phonological learning, albeit uni- or bidirectionally.

A second motivating consideration draws upon conventional clinical literature, where NWs have been advocated in a number of instructional programmes (Shames, 1957; Van Riper, 1963; Gerber, 1973; Winitz, 1975; Hoffman, Shuckers, and Daniloff, 1989). In such programmes, NWs are typically coupled with RWs, sequenced as successive stimulus sets in treatment; however, the justification for NW use varies. Shames (1957), for example, argued that NWs help a child transition from deliberate to automatic productions. Hoffman et al. (1989) said NWs focus a child’s attention on articulatory routines. Gerber (1973) equated NWs with novel visual referents. Here, the thought was that the newness of the treated NWs (both phonologically and referentially) would reduce interference from errored productions, and thereby facilitate transfer. Despite these similarities and differences, there is little empirical evidence to document the function, utility, or necessity of NWs for phonological learning.

A third motivating factor draws upon the research literature. In one body of work, it has been shown that NWs (at least certain types) result in production accuracy of sounds (Hewlett, Gibbon, and Cohen-McKenzie, 1998; Beckman and Edwards, 2000a). Children with phonological disorders appear to produce sounds correctly when these are elicited in imitation of NWs. This hints that NWs may benefit children’s production, but it does not speak to the issue of phonological learning. The reason is that the data were elicited in imitation, which does not necessarily translate to internal knowledge of the sound system. Also, the data were sampled at a single static point in time, so the longitudinal benefits that might accrue from NWs are as yet unknown. There is, however, a body of treatment research that has employed NWs in the context of children’s phonological learning (e.g.

[1]Under some clinical descriptions (e.g. Hodson and Paden, 1983; Fey, 1992), a distinction is made between articulatory and phonological disorders. Within linguistics, this distinction is unnecessary because the formal study of phonology incorporates phonetic and phonemic structure, along with rule-governed phonological changes, in a parsimonious model comprised of multiple levels of representational structure (Chomsky and Halle, 1968; McCarthy, 2002; see also Dinnsen, 1984; Gierut, 2001 for clinical applications). The present work is framed within this linguistic perspective.

McReynolds, 1972; Elbert and McReynolds, 1978; Powell and Elbert, 1984; Gierut, 1992). In that work, NWs were used strictly for methodological purposes as a means of ensuring stimulus control in treatment, both within and across children and studies. By exposing participants to the same NW sequences, the range of stimulus variability was reduced, and spurious effects associated with word familiarity, word frequency, or age-of-word-acquisition were further eliminated (Gierut, 2008b). While NWs afforded certain methodological advantages in prior treatment studies, it should be noted that NWs were not the explicit focus of study, nor were they manipulated as the independent variable relative to RW input. Consequently, any statements that might be drawn about the effects of NWs on phonological learning are inferential at best. The differential contribution of NWs vs RWs thus remains for empirical demonstration.

A fourth motivation for the present study follows from the results of a retrospective investigation of 60 children with phonological disorders, who had been exposed to either RWs or NWs in treatment (Gierut, Morrisette, and Ziemer, 2009). In that study, RW and NW stimuli were phonotactically permissible sequences that had been assigned semantic meaning, consistent with the protocols of Gerber (1973) and Leonard (1973). The groups of children were treated using the differential stimuli, and generalization to treated and untreated sounds was monitored at post-treatment and longitudinally following the completion of treatment. The results that emerged hinted that NWs might have an early facilitating effect on phonological generalization, perhaps serving as a jumpstart to learning. That study was limited, however, due to its post-hoc nature. Prospective study is now warranted to thoroughly document the detailed effects of NW stimuli on learning during phonological treatment, and also on generalization.

The goal of the present study was to experimentally evaluate the role that lexicality plays in children's productive phonological learning. As a first step, this study was limited to an examination of children's production accuracy of treated sounds when these were taught in RW vs NW stimuli. By holding the phonological characteristics of the stimuli constant, lexicality served as the single independent variable, with session-by-session learning in treatment being monitored as the dependent variable. Our initial intent was to delineate how NWs might bear on the session-by-session effects and efficiency of phonological treatment when compared to RWs. Based on the motivating literature, the expectation was that lexicality will influence children's learning, with a prediction that treated sounds will show greater production accuracy when taught using NWs as stimuli.

Method

Participants

Children with functional phonological disorders were recruited from area schools and day care centres. As eligibility for participation, children were to exhibit typical performance on a battery of tests including hearing acuity, oral motor structure and function, receptive and expressive vocabulary, receptive and expressive language, and non-verbal intelligence (Gierut, 2008b). Inclusionary criteria also required that the children be monolingual speakers of English between the ages of 3–7 years.

With respect to the phonology, standard scores of 85 or lower on the *Goldman-Fristoe Test of Articulation–2nd edition* (Goldman and Fristoe, 2000) were required for participation. In addition, children were to present with a reduced consonantal inventory, excluding a minimum of six target English phonemes in all relevant contexts. Sounds excluded from the inventory were identified based on the results and analyses of extensive probe measures. The probes that were used have been employed previously in the phonological acquisition literature (Gierut, Elbert, and Dinnsen, 1987; Gierut, 2008b). These sampled all target

English sounds in multiple exemplars and contexts, and were elicited using a spontaneous picture-naming task. Children's production responses to the probes were digitally recorded, and then phonetically transcribed by a trained listener using narrow notation of the IPA. Reliability of phonetic transcriptions was established by having an independent judge also transcribe the probe data. Point-to-point comparisons of consonant transcriptions were made against the originals. Mean transcription agreement between judges was 93% (range: 90–95% agreement with 517 segments transcribed). The resulting transcriptions were then submitted to standard descriptive phonological analyses (Dinnsen, 1984; also, Chomsky and Halle, 1968) to establish children's phonetic and phonemic inventories, distribution of sounds, phonotactic constraints, and phonological rules. Based on these analyses, the target sounds that were excluded from a given child's phonemic inventory were identified, having been produced with 0% accuracy in all word positions and in the absence of minimal pairs.

Four children who met these criteria were identified: three boys and one girl, having a mean age of 4 years, 6 months. Demographic and phonological information about the children are reported in Table I, along with their experimental assignments.

Experimental design

Overview—A complex single-subject design was used, incorporating an alternating treatments design (ATD) with a staggered multiple baseline (MBL) across subjects design. The intended purpose of the ATD is to test the efficacy of two or more treatments as applied to a given learner (Hersen and Barlow, 1976; Kazdin and Hartmann, 1978; Barlow and Hayes, 1979; McReynolds and Kearns, 1983). In the basic set-up, a learner is exposed to two or more treatment conditions concurrently. The conditions are randomly and rapidly varied within a session. The assumption is that a learner will recognize the difference between conditions, such that one treatment will emerge as preferred over the other as evidenced by differential learning. The divergence in learning is thought to reveal the treatment condition that is relatively more efficacious or 'optimal'.

Because the ATD is intended to be the first step in establishing the differential effects of competing treatments, it does not require many of the usual controls that are the hallmark of single-subject designs (Barlow and Hayes, 1979: 207). Consequently, the staggered MBL across subjects design is often overlaid on the ATD to ensure experimental control (Kearns, 1986; Thompson and McReynolds, 1986; see Gierut et al., 1996 for illustration). The intended purpose of the staggered MBL is to demonstrate that treatment is responsible for any observed changes in learning. Learners are sequentially phased in to an experiment, with the number of baselines increasing by 1 with each successive enrolment. The assumption is that a learner's performance will remain stable during baseline, with change in behaviour occurring coincident with treatment; hence, treatment is said to be responsible for the observed behavioural change (Hersen and Barlow, 1976: 226–229; McReynolds and Kearns, 1983: 53).

As applied in this study, the ATD provided for the use of RWs and NWs as stimuli in treatment of a given child. The MBL across subjects provided for experimental control and replication of effects.

Experimental assignment—Children were paired for purposes of counterbalance and replication. As shown in Table I, Children 1 and 2 were paired, with each being treated on /l θ/. Child 1 was taught /l/ in RWs and /θ/ in NWs within the context of the ATD. For Child 2, it was just the reverse. Likewise, Children 3 and 4 were paired, and each treated on /ɡ θ/. Child 3 was taught /ɡ/ in RWs and /θ/ in NWs, with the reverse assignment for Child 4. Within each pairing, the number of baselines that was administered to each child was incremented by 1 in order to accommodate the staggered phase-in of the MBL design; this is reported in Table I.

The specific treated sounds were chosen because they were phonotactically excluded from the children's inventories, being produced with 0% accuracy on pre-treatment probes. Treated sounds reflected common error patterns among children with phonological disorders, i.e. velar fronting in the case of /ɡ/, stopping of fricatives in the case of /θ/, and liquid gliding in the case of /l/ (Stoel-Gammon and Dunn, 1985). Treated sounds were further drawn from mid- and late-8 categories based on order of sound acquisition (Shriberg, 1993), with /ɡ/ being a mid-8 target and /θ l/, late-8 targets. Moreover, treated sounds represented the major classes of obstruents (i.e. /ɡ θ/) and sonorants (i.e. /l/).

The rationale for considering these properties in selection of treated sounds was to afford a more detailed evaluation of the ways in which lexicality may impact children's phonological learning. For example, if specific sounds or error patterns were to be differentially affected by lexicality, this would be revealed in comparisons of the learning patterns associated with treatment of /ɡ θ l/ (alternatively, fronting, stopping, liquid gliding). Likewise, if order of sound acquisition were to be differentially affected by lexicality, then this could be pinpointed by comparing the learning of mid- and late-8 treated sounds. Finally, if major class were to be differentially affected by lexicality, then comparisons of obstruents vs sonorants would be revealing. In all, the experimental assignments and corresponding treated sounds allowed for a broad evaluation of learning as attributed to the lexicality of the treated stimuli, with and/or without the further contribution of treated sound, error pattern, order of sound acquisition, or major class.

Design implementation—Consistent with the ATD and procedures used previously in the literature (e.g. Gierut, 1992; Gierut and Neumann, 1992; Gierut et al., 1996), children were exposed to both experimental conditions within each treatment session. Each session was 1-hour in duration, meeting three times weekly. Half the session was devoted to the treatment of a specific target sound in the initial position of 8 RW stimuli, and the other half to the treatment of the alternate target sound in the initial position of 8 NW stimuli. The order of administration of RW/NW conditions was randomly varied across sessions. For example, in the first session of treatment, Child 1 was taught /l/ in RWs, followed by /θ/ in NWs. The order was then randomly switched in subsequent sessions. Between training blocks, there was a brief rest, during which time the child participated in a play activity (e.g. puzzle, building blocks, board game). According to principles of the ATD, the randomized order of presentation is needed to isolate any potentially interfering crossover or additive effects between experimental conditions, whereas the break between conditions is used to signal the treatment shift for the learner (Kazdin and Hartmann, 1978: 918–920; Barlow and Hayes, 1979: 204–209; McReynolds and Kearns, 1983: 185–192).

Treatment proceeded in two phases (Gierut, 2005; 2008a): imitation followed by spontaneous production of the treated sounds in the experimental stimuli. During imitation, a child repeated the clinician's model of the treated item, and was provided with 1:1 feedback about the accuracy of responding. The imitation phase continued for a total of seven sessions or until a child achieved 75% accuracy of production of the treated sound in the treated stimuli over two consecutive sessions, whichever occurred first. This was then followed by spontaneous production of the treated sound in the same treated stimuli. During the spontaneous phase, a child named the treated item without a model, and was again provided with 1:1 feedback about accuracy of responding. The spontaneous phase continued for 12 total sessions or 90% accuracy of production over three consecutive sessions, whichever occurred first. On average, 31 responses were elicited from each child, per condition, per session.

Stimuli

RW and NW stimuli were developed specific to each of the treated sounds /ɡ θ l/; thus, there were six stimulus sets in all. These are listed in Table II. Each set was comprised of eight items, with the treated sound always occurring in initial position. Within each set of eight, there were five CVC, two CVCV, and one CVCVC canonical shapes. Also, within each set, five treated items were nouns, and the remaining three items left free to vary by grammatical category.

Stimuli were crafted so that RWs and NWs were as near to identical as possible, recognizing that RWs were to be legitimate words of the English language, whereas NWs were to be novel, referentially and phonotactically. With this in mind, RWs were selected from the reference vocabularies of words that are reportedly known by children (Gilhooly and Logie, 1980; Moe, Hopkins, and Rush, 1982; Bird, Franklin, and Howard, 2001). Seventy-nine per cent of the RWs (19 of 24 total) were drawn from these reference databases. Their average frequency was 80 occurrences per 6412 words (Moe et al., 1982). The remaining items that comprised the RW set were chosen from words used in children's literature and song (Malloy, 1980; Brown, 1996; Cosgrove, 2001; Hixon, 2004). By these criteria, the RWs of this study were deemed familiar and appropriate to children. NWs were next constructed by changing the consonant composition of a RW to yield a novel form, using the segments /m n b d/ as target replacements. For example, as in Table II, RW [θɪk] became NW [θɪb], when [b] was swapped for [k] of 'thick'. As another example, RW [ɡɛs] became NW [ɡɛm], when [m] replaced [s] of 'guess'. This made the general phonological form of the RWs and NWs similar.

To further ensure that the phonological composition of the stimulus sets was comparable, the phonotactic probability of the stimuli was computed. Recall that phonotactic probability reflects the likelihood of occurrence of sounds and sound sequences in the language. Conventionally, two dimensions are examined, sum of positional segment frequency and sum of biphone frequency (Vitevitch and Luce, 2004). *Sum of segment frequency* reveals how often a given sound occurs in a given word position relative to all other permissible sounds in that same position. *Sum of biphone frequency* detects how often pairs of sounds co-occur relative to all other legal co-occurrences. In this study, the sums of positional segment and biphone frequencies were calculated for both the RW and NW stimulus sets. A publicly available calculator (Vitevitch and Luce, 2004; http://www.people.ku.edu/~mvitevit/PhonoProbHome.html) was used, with z-score conversion for word length (Storkel, 2004b). The corresponding mean values associated with lexicality are reported in Table III. A t-test for independent samples showed no statistically reliable difference between RW and NW stimuli in the adjusted positional segment frequency, $t(62) = .39$, $p = .70$, or the adjusted biphone frequency, $t(62) = 1.37$, $p = .18$. The number of phonemes that comprised the RW and NW sets were also not statistically different, $t(62) = -.19$, $p = .85$.

Neighbourhood density was also determined to equate the possible influences of lexical competition on phonological learning across RW and NW stimulus sets. Recall that neighbourhood density refers to the number of phonetically similar counterparts to a given word, based on 1-phoneme substitutions, deletions, or additions (Luce, 1986). To determine neighbourhood density for the respective stimulus sets, the Hoosier Mental Lexicon (Nusbaum, Pisoni, and Davis, 1984) was consulted, as accessed at http://www.bncdnet.ku.edu/cgi-bin/DEEC/post_ccc.vi. This is a publicly available database comprised of 20,000 words of the English language, which has a neighbourhood search function. As in Table III, the search revealed that RW stimuli had a mean density of 12 neighbours (range 0–32), and NW stimuli, a mean density of nine neighbours (range 0–28). A *t*-test for independent samples showed no statistically reliable difference between RW and NW stimuli in terms of their density, $t(46) = 1.28$, $p = .21$.

In all, RW and NW stimulus sets resembled each other in canonical shape, grammatical category, overall phonological form, phonotactic probability, and neighbourhood density.

Materials

Once the RW and NW sets had been established, the forms were then affiliated with stories and pictures to be used as materials during treatment. These were specific to each treated sound; however, across conditions, the same visual stimuli were used, with the only difference again being the lexicality of the labels that were assigned. This is best illustrated in Table IV for the treated sound /ɡ/ (e.g. ‘His name is Gary’ for the RW condition vs ‘His name is [ɡɛbi]’ for the NW condition).

Stories were first used to introduce the stimuli, and to provide a contextual frame for the treated items, which was relevant to the case of NWs (Gierut, 2005). Within each session, at the start of each condition, the child viewed a series of slides depicting the story plot. Each slide was presented by computer and viewed for ~ 2 seconds. There was no corresponding auditory input except on specifically designated slides. On the designated slide, the child heard the relevant sentence from the story, and it contained one of eight items to be treated, repeated twice. Following the above example (also Table IV), the child would have heard ‘His name is *Gary*. *Gary* has a moustache and a long beard’ when shown the corresponding picture in the story. All stories were pre-recorded and spoken by a female speaker. All stories were 120 words in length; their spoken duration was 7 seconds. During the story presentation, a child was to simply listen and attend to the story.

Following the initial listening period, eight picture cards were introduced specific to the given experimental condition. Pictures were specific to each treated sound, and were black-and-white renditions of the stimulus items that had been presented previously in the stories. These were used session-by-session in treatment to elicit children’s productions.

Dependent variable

Accuracy of production of the treated sound in the treated RWs vs NWs was the dependent variable. These data came from a child’s performance in the treatment sessions, and were scored in real time for accuracy of production by the administering clinician. These data were used to determine advancement through the treatment phases and reflected a child’s learning during treatment. They also established the relative preferred teaching condition as revealed by the ATD.

Treatment fidelity was established to ensure reliability of protocol administration and scoring. A checklist procedure had been developed, and is used as part of the standard protocol of the Learnability Project (Gierut, 2008b). The checklist documents whether an administering clinician uses the appropriate stimuli (NWs or RWs), presents these in a predetermined randomized order, elicits the required number of trials per session, incorporates drill play to elicit responses, provides a model during the imitation phase of treatment and no model during the spontaneous phase, judges the accuracy of a child’s production relative to the adult target, provides feedback for each production elicited, scores each production elicited, and correctly computes the percentage accuracy of production for each session. Using this checklist, an independent observer, who was trained to run the experimental protocol and to apply the fidelity checklist, monitored 11% of all treatment sessions. Fidelity was estimated to be 100%, such that the administering clinician assembled and delivered the stimuli, provided modelling and feedback, collected and scored production accuracy, and computed percentage accuracy of production in accord with the protocol.

Consistent with the structure of single-subject design (McReynolds and Kearns, 1983), the resulting learning data were evaluated through visual inspection relative to lexicality of the treated stimuli as the independent variable.

Results

Figures 1 and 2 report the results from the two pairs of children. The data that are shown reflect the percentage accuracy of production of the treated sound, as elicited in RWs vs NWs during the course of session-by-session treatment. Beginning with the data in Figure 1, it can be seen that, at pre-treatment, there was 0% accuracy of the treated sounds /θ l/ for this pair of children. It can also be seen that both children evidenced greater production accuracy of the sound that was treated in NWs. For Child 1, as the first participant in the MBL sequence, production of /θ/ was in the range of 80–100%accuracy when taught in NWs, as compared to production of /l/, in the range of 28–63% accuracy when taught in RWs. While /θ/ reached ceiling levels of production accuracy by the third session of treatment, /l/ experienced a return to 0% baseline performance. In all, Child 1 required five treatment sessions to complete the experimental protocol (see Design implementation section), and, at that time, production of /θ/ was nearly 40% greater than production of /l/.

Child 2 served as the replicant and counterbalanced case, with /l/ being affiliated with NWs and /θ/ with RWs. This child's learning was protracted, with 19 treatment sessions required to move through the protocol. This not withstanding, Child 2 also showed greater accuracy of production for /l/ when treated in NWs than /θ/ in RWs. At any given point in the treatment sequence, production /l/ was, on average, 20% more accurate than production of /θ/.

Figure 2 shows the learning curves for a second pair of children. The results are much the same, but accelerated. Again, both children started with 0% accuracy of /θ ɡ/ at pre-treatment. While there was an early edge in accuracy associated with treatment of sounds in NWs, both children reached ceiling levels of performance. For Child 3, 100% production accuracy of /θ/ in NWs was achieved in the second treatment session, and /θ/ remained at that level throughout the duration of the protocol. Child 3's production of /ɡ/ in RWs followed behind, with 100% accuracy achieved in the final treatment session. For Child 4, as the counterbalanced replicant, 100% accuracy of production of /ɡ/ in NWs was achieved after the first treatment session, with 100% production of /θ/ in RWs being not far behind (day 2).

When the data in Figures 1 and 2 are taken together, a conservative summary is that treatment of a sound in NWs resulted in a level of accuracy that was at least as good as, or better than treatment of a sound in RWs. This observation bears on treatment effects (Olswang, 1998). It also appeared that NWs promoted a level of accuracy in the treated sound sooner in the course of treatment, compared to when that same level of gain might have been observed for RWs. This bears on treatment efficiency (Olswang, 1998).

The results further suggested that the effects of lexicality might be independent of phonological factors, including treated sound/error pattern, order of sound acquisition, or major class. This suggestion stems from the observation that similar benefits accrued across children in the counterbalanced and replicated cases. To illustrate, /θ/ in NWs exceeded /l/ in RW for Child 1, but it was just the reverse phoneme advantage for Child 2. Thus, the lexicality effects were not specific to treated sound. Similarly, NWs positively affected three different error patterns, liquid gliding for Child 1, stopping for Children 2 and 3, and fronting for Child 4. Hence, the lexicality effects were not restricted to specific error patterns. Likewise, the lexicality effects were not influenced by order of sound acquisition because production of both late-8 and mid-8 sounds improved with treatment of NWs (e.g. Children 3 and 4, respectively). In addition, the beneficial effects of NWs appeared to cross-cut major classes. There was greater production accuracy associated with NWs, no matter that a treated sound was an obstruent (i.e. Children 1, 3, 4) or a sonorant (i.e. Child 2). For children of this study, the potential NW advantage did not appear to be influenced by the phonological factors that were considered in the design.

Clinical implications

There are applied consequences that derive from the results, which may bear on the administration and efficacy of phonological treatment. Because NWs appeared to improve the accuracy and efficiency of learning a treated sound, a possible clinical recommendation is that sounds be treated in NW stimuli to enhance treatment efficacy. This recommendation is consistent, at least in part, with the outline of a number of other conventional clinical programmes (Van Riper, 1963; Winitz, 1975). While prior instructional programmes advocated the use of NWs in treatment, they did so largely in the absence of an empirical demonstration of the NW effects on phonological learning; the present findings now offer preliminary experimental validation. Prior instructional programmes also advocated that NWs be succeeded by RWs later in the course of treatment. While the present study did not sequence a NW treatment step followed by a RW treatment step, it may be that NWs alone provide sufficient input to support the accurate production of treated sounds (see also McReynolds, 1972; McReynolds and Elbert, 1981; Elbert and McReynolds, 1985). This possibility is supported by the observation that three of four children who participated in this study reached 100% accuracy of production of the treated sound with exposure to NWs.

These findings are consistent with, and extend the results of descriptive research that has shown, post-hoc, an advantage for NWs (Gierut et al., 2009). In that work, NWs promoted generalization to treated and untreated sounds, and these changes occurred coincident with, and causal to treatment. The present study begins to extend the prior observations in four new ways. First, the research reported herein was prospective and experimental, complementing the prior post-hoc description. Secondly, the present study focused on acquisition of treated sounds in NWs, complementing the prior examination of generalization. Thirdly, the present study considered the efficiency of NWs in inducing phonological gains session-by-session during the course of treatment. This complements the prior examination of post-treatment effects. Fourthly, the present study documented longitudinal phonological acquisition. This extends prior work (Hewlett et al., 1998; Beckman and Edwards, 2000a), which has shown that children's production of an errored sound in NWs is more accurate than in RWs, when sampled in imitation and at a single point in time.

These additions notwithstanding, the present study has its limitations. The clinical potential of NWs appears to hold promise, but it remains for future research to establish more comprehensively the unique and complementary contributions of NW and RW stimuli to phonological learning. While the present study represents a first step, it was limited in sample size, and, consequently, number of replications of the learning effects. The ATD also has inherent limitations, given its expressed purpose as an initial run to differentiate among conditions of treatment. The design sidesteps an important consideration in the delivery and design of phonological treatment, namely, the induction of system-wide generalization. In future prospective research, it will be important to extend the present study by recruiting a larger cohort of children who display a broader range of error patterns and/or phonotactic exclusions. In the present study, treatment was directed at children's inventory constraints to ensure stable 0% baseline performance; however, treatment may also be applied to distributional restrictions or phonological rules in subsequent studies. It will also be necessary to explore the use of alternate experimental designs that provide broadly for phonological generalization.

Continued research is also needed to place NWs in the larger context of evidence-based practice. One recommendation is that complexity approaches to treatment (Gierut, 2001; 2007) offer an advantage for phonological learning. It is not yet known, however, whether factors such as typological markedness might interface with the use of NWs in treatment. This remains a question of study. Another recommendation is that high frequency RWs aid generalization when compared to low frequency RWs (Morrisette and Gierut, 2002). While the effects of RW frequency are known, high vs low frequency RWs have not been systematically varied relative to NWs. Further, the effects of high vs low frequency RWs have not been documented for mastery of a treated sound, session-by-session, over the duration of treatment. These too remain open questions. Through continued research along these lines, it is likely that the robustness of NW effects will be revealed. The results to emerge will serve to inform clinical decisions about which children might benefit from NWs, under which treatment conditions, and with what success.

Theoretical implications

There are at least two theoretical perspectives that bear on a possible interpretation of the present findings, as outlined in the introduction. Recall that one view is that lexical learning serves as a bootstrap to phonological learning, with novel word learning perhaps unidirectionally supporting the acquisition of the sound system (e.g. Jakobson, 1941/1968). The results of the present study are consistent with this view, but only in part. It is true that the treated NWs had a positive effect on children's phonological learning, and that these had also been assigned new and unique meanings in a story context. However, the focus of treatment necessitated that children accurately produce the sounds that comprised the NWs. Consequently, in treatment, children were expected to learn *both* the novel meaning and the phonological form of the treated NWs. This was especially evident in the spontaneous phase of instruction, where children were to accurately produce the NWs in association with corresponding pictures that depicted their meanings. As such, it is not possible to establish the exact contributions of NW form and/or NW meaning to phonological learning for the children of this study. Unlike what has been put forth for typical development, it cannot be said that lexical learning was the dominant factor that unidirectionally guided children's phonological learning based on the present findings. It remains for future research to delineate the relative contributions of form and meaning to phonological learning (cf. Naigles, 2002 for lexical development), particularly as observed in clinical settings.

The present findings may be considered in the alternate context of a bi-level, bidirectional model of lexical and phonological learning (Storkel and Morrisette, 2002). Recall that this framework makes a distinction between lexical information that is derived on the basis of the properties of a whole word as a unit (e.g. a given word's frequency), and sub-lexical information that describes the properties of sounds that make up the word (e.g. phonotactic probability). One hypothesis is that RWs trigger lexical structure, whereas NWs trigger sub-lexical structure (Vitevitch and Luce, 1998; 1999; Vitevitch, Luce, Pisoni, and Auer, 1999; Vitevitch, Armbrüster, and Chu, 2004). This proposal has been empirically demonstrated in studies of perception (Vitevitch, 2002a; 2003), production (Vitevitch, 1997; 2002b), and processing (Vitevitch et al., 1999), whereby lexicality differentially influenced participants' behaviour. By extension, if NWs highlight sub-lexical (i.e. phonological) structure, then it is possible that similar effects may have obtained in the present treatment study. NWs may have brought the sound structure of the treated stimuli to the forefront, and this, in turn, may have promoted children's phonological learning. In future research, it will be necessary to continue to tease apart the contributions of lexical and sub-lexical structure to phonological learning (cf. Storkel, Armbrüster, and Hogan, 2006 for lexical learning), particularly as it bears on the delivery of clinical treatment.

While the theoretical possibilities are attractive, it is also necessary to take a step back to look at the potential effects of novelty on phonological learning. In the present study, NWs were clearly unique: they did not occur in the native language, and children would not have heard them in the input. However, it is also the case that children have limited vocabularies. Accordingly, any number of RWs in the language may be novel to children, albeit in form and/or meaning. Moreover, children’s home environments vary, so they may receive unique amounts of input about unique sub-sets of RWs. RWs that are familiar to some children may not be familiar to others. When viewed in the context of the present study, it is possible that some of the RWs used in treatment (Table II) may have been new to some of the children. Despite the fact that measures were taken to ensure that RWs were selected from child corpora, certain RWs (like NWs) may have been novel and unique. Consider then that, if novelty were responsible for the observed learning effects, it is possible that *any* unique stimulus that is introduced in phonological treatment may have a beneficial effect on production accuracy. Unique items may draw and hold a child’s attention to thereby facilitate learning. Yet, if a novelty effect were operative, it would also be short lived (Murphy, 2002) because the newness of a stimulus wears off with repeated exposures. In treatment, a child would eventually habituate to novel stimuli, with the presumed benefits to learning likewise showing plateaus or declines. Thus, the effects of novelty would be identifiable in children’s learning patterns, with facilitation of production accuracy early in treatment, followed by declines in production accuracy of the very same stimulus items later in treatment. To our knowledge, the effects of novelty have not yet been explored relative to phonological learning (cf. Saffran and Thiessen, 2003 for lexical learning), and thus remain a question for future clinical research. This line of study may have added theoretical prospects because it may reveal the role of executive function (i.e. attention) in the performance of children with phonological disorders.

In sum, this examination of lexicality offered some preliminary practical suggestions about the kinds of stimuli to be used in phonological treatment to enhance production accuracy of the treated sound. Namely, NWs may be at least as good as, or perhaps better than RWs in improving the effects and efficiency of treatment. This study also raised some relevant theoretical questions about the ways that word learning may steer or cooperate with phonological learning. Of particular interest are the potential (and perhaps also differential) contributions of form and meaning, lexical and sub-lexical structure, and attention to children’s phonological learning in treatment. Together, the clinical and theoretical issues may shape future research for a better understanding of the liaison between phonology and the lexicon in language development.

Acknowledgments

This research was supported, in part, by a grant from the National Institutes of Health (NIDCD 0001694) to Indiana University. We would like to thank members of the Learnability Project for assistance with data transcription, management, and analysis. Suzanne M. Ziemer contributed in early phases of the study, and Dan Dinnsen provided input throughout.

References

Barlow DH, Hayes SC. Alternating treatments design: one strategy for comparing the effects of two treatments in a single subject. Journal of Applied Behavior Analysis. 1979; 12:199–210. [PubMed: 489478]

Beckman, ME.; Edwards, J. Lexical frequency effects on young children's imitative productions. In: Broe, M.; Pierrehumbert, J., editors. Papers in laboratory phonology V. Cambridge, UK: Cambridge University Press; 2000a. p. 207-217.

Beckman ME, Edwards J. The ontogeny of phonological categories and the primacy of lexical learning in linguistic development. Child Development. 2000b; 71:240–249. [PubMed: 10836579]

Bird H, Franklin S, Howard D. Age of acquisition and imageability ratings for a large set of words, including verb and function words. Behavior Research Methods, Instruments, & Computers. 2001; 33:73–79.

Brown, M. Arthur's chicken pox: An Arthur adventure. New York: Little, Brown Books for Young Readers; 1996.

Bybee, JL. Phonology and language use. Cambridge, UK: Cambridge University Press; 2001.

Charles-Luce J, Luce PA. Similarity neighbourhoods of words in young children's lexicons. Journal of Child Language. 1990; 17:205–215. [PubMed: 2312642]

Cholin J, Levelt WJM, Schiller NO. Effects of syllable frequency in speech production. Cognition. 2005; 99:205–235. [PubMed: 15939415]

Chomsky, N.; Halle, M. The sound pattern of English. New York: Harper and Row; 1968.

Cosgrove, S. Crabby Gabby. New York: Price Stern Sloan; 2001. (R. James, Illus.).

Dinnsen, DA. Methods and empirical issues in analyzing functional misarticulation. In: Elbert, M.; Dinnsen, DA.; Weismer, G., editors. Phonological theory and the misarticulating child (ASHA Monographs No. 22). Rockville, MD: American Speech-Language-Hearing Association; 1984. p. 5-17.

Dinnsen DA, Chin SB, Elbert M, Powell TW. Some constraints on functionally disordered phonologies: phonetic inventories and phonotactics. Journal of Speech and Hearing Research. 1990; 33:28–37. [PubMed: 2314081]

Edwards J, Beckman ME, Munson B. The interaction between vocabulary size and phonotactic probability effects on children's production accuracy and fluency in nonword repetition. Journal of Speech, Language, and Hearing Research. 2004; 47:421–436.

Elbert M, McReynolds LV. Transfer of /r/ across contexts. Journal of Speech and Hearing Disorders. 1975; 40:380–387. [PubMed: 1234951]

Elbert M, McReynolds LV. An experimental analysis of misarticulating children's generalization. Journal of Speech and Hearing Research. 1978; 21:136–150. [PubMed: 642482]

Elbert M, McReynolds LV. The generalization hypothesis: final consonant deletion. Language and Speech. 1985; 28:281–294. [PubMed: 3836317]

Ferguson CA, Farwell CB. Words and sounds in early language acquisition: English initial consonants in the first fifty words. Language. 1975; 51:419–439.

Fey ME. Articulation and phonology: inextricable constructs in speech pathology. Language, Speech and Hearing Services in Schools. 1992; 23:225–232.

Gerber, A. Goal: Carryover. Philadelphia: Temple University; 1973.

Gierut JA. The conditions and course of clinically-induced phonological change. Journal of Speech and Hearing Research. 1992; 35:1049–1063. [PubMed: 1447917]

Gierut JA. Complexity in phonological treatment: clinical factors. Language, Speech and Hearing Services in Schools. 2001; 32:229–241.

Gierut, JA. Phonological intervention: the how or the what?. In: Kamhi, AG.; Pollack, K., editors. Phonological disorders in children: Assessment and intervention. Philadelphia: Brookes; 2005. p. 201-210.

Gierut JA. Phonological complexity and language learnability. American Journal of Speech-Language Pathology. 2007; 16:1–12.

Gierut, JA. Fundamentals of experimental design and treatment. In: Dinnsen, DA.; Gierut, JA., editors. Optimality theory, phonological acquisition and disorders. London: Equinox; 2008a. p. 93-118.

Gierut, JA. Phonological disorders and the Developmental Phonology Archive. In: Dinnsen, DA.; Gierut, JA., editors. Optimality theory, phonological acquisition and disorders. London: Equinox; 2008b. p. 37-92.

Gierut JA, Elbert M, Dinnsen DA. A functional analysis of phonological knowledge and generalization learning in misarticulating children. Journal of Speech and Hearing Research. 1987; 30:462–479. [PubMed: 3695441]

Gierut JA, Morrisette ML, Champion AH. Lexical constraints in phonological acquisition. Journal of Child Language. 1999; 26:261–294. [PubMed: 11706466]

Gierut JA, Morrisette ML, Hughes MT, Rowland S. Phonological treatment efficacy and developmental norms. Language, Speech and Hearing Services in Schools. 1996; 27:215–230.

Gierut JA, Morrisette ML, Ziemer S. Nonwords and generalization in children with phonological disorders. 2009 Manuscript submitted for publication.

Gierut JA, Neumann HJ. Teaching and learning /θ/: a nonconfound. Clinical Linguistics & Phonetics. 1992; 6:191–200. [PubMed: 21269158]

Gierut JA, Simmerman CL, Neumann HJ. Phonemic structures of delayed phonological systems. Journal of Child Language. 1994; 21:291–316. [PubMed: 7929683]

Gilhooly KJ, Logie RH. Age-of-acquisition, imagery, concreteness, familiarity, and ambiguity measures for 1,944 words. Behavior Research Methods, Instruments and Computers. 1980; 12:395–427.

Goldman, R.; Fristoe, M. Goldman-Fristoe test of articulation. 2nd ed. Circle Pines, MN: American Guidance Service; 2000.

Goodman JC, Dale P, Li P. Does frequency count? Parental input and the acquisition of vocabulary. Journal of Child Language. 2008; 35:515–531. [PubMed: 18588713]

Hersen, M.; Barlow, DH. Single case experimental designs: Strategies for studying behavior change. New York: Pergamon; 1976.

Hewlett N, Gibbon F, Cohen-McKenzie W. When is a velar an alveolar? Evidence supporting a revised psycholinguistic model of speech production in children. International Journal of Language & Communication Disorders. 1998; 33:161–176. [PubMed: 9709435]

Hixon, MU. Turtle's way: Loggy, Greeny, and Leather. Melbourne Beach: Canmore Press; 2004. (S.J. Harris, Illus.).

Hodson, BW.; Paden, EP. Targeting intelligible speech: A phonological approach to remediation. Boston: College-Hill; 1983.

Hoffman, PR.; Shuckers, G.; Daniloff, RG. Children's phonetic disorders: Theory and treatment. Austin, TX: Pro-Ed; 1989.

Jakobson, R. Child language, aphasia, and phonological universals. Keiler, AR., translator. The Hague: Mouton; 1941/1968.

Jusczyk PW, Luce PA, Charles-Luce J. Infants' sensitivity to phonotactic patterns in the native language. Journal of Memory and Language. 1994; 33:630–645.

Kazdin AE, Hartmann DP. The simultaneous-treatment design. Behavior Therapy. 1978; 9:912–922.

Kearns KP. Flexibility of single-subject experimental designs, Part II: design selection and arrangement of experimental phases. Journal of Speech and Hearing Disorders. 1986; 51:204–213. [PubMed: 3525987]

Leonard LB. Referential effects on articulatory learning. Language and Speech. 1973; 16:45–56.

Leonard LB, Ritterman SI. Articulation of /s/ as a function of cluster and word frequency of occurrence. Journal of Speech and Hearing Research. 1971; 14:476–485. [PubMed: 5163881]

Luce PA. A computational analysis of uniqueness points in auditory word recognition. Perception and Psychophysics. 1986; 39:155–158. [PubMed: 3737339]

Malloy, J. Bad Thad. New York: Dutton Children's Books; 1980. (M. Alexander, Illus.).

Maye, J.; Gerken, L. Learning phonemes without minimal pairs. In: Howell, SC.; Fish, SA.; Keith-Lucas, T., editors. Proceedings of the 24th Annual Boston University Conference on Language Development. Somerville, MA: Cascadilla Press; 2000. p. 522-533.

McCarthy, JJ. A thematic guide to optimality theory. Cambridge: Cambridge University Press; 2002.

McReynolds LV. Articulation generalization during articulation training. Language and Speech. 1972; 15:149–155. [PubMed: 4653681]

McReynolds LV, Bennett S. Distinctive feature generalization in articulation training. Journal of Speech and Hearing Disorders. 1972; 37:462–470. [PubMed: 4648936]

McReynolds LV, Elbert MF. Generalization of correct articulation in clusters. Applied Psycholinguistics. 1981; 2:119–132.

McReynolds, LV.; Kearns, KP. Single-subject experimental designs in communicative disorders. Baltimore, MD: University Park; 1983.

Moe, AJ.; Hopkins, CJ.; Rush, RT. The vocabulary of first-grade children. Springfield, IL: Charles C Thomas; 1982.

Morrisette ML, Gierut JA. Lexical organization and phonological change in treatment. Journal of Speech, Language, and Hearing Research. 2002; 45:143–159.

Munson B. Phonological pattern frequency and speech production in adults and children. Journal of Speech, Language, and Hearing Research. 2001; 44:778–792.

Munson B, Kurtz B, Windsor J. The influence of vocabulary size, phonotactic probability, and wordlikeness on nonword repetitions of children with and without specific language impairment. Journal of Speech, Language, and Hearing Research. 2005; 48:1033–1047.

Munson B, Solomon NP. The effect of phonological neighborhood density on vowel articulation. Journal of speech, Language, and Hearing Research. 2004; 47:1048–1058.

Murphy, GL. The big book of concepts. Cambridge, MA: MIT Press; 2002.

Naigles LR. Form is easy, meaning is hard: resolving a paradox in early child language. Cognition. 2002; 86:157–199. [PubMed: 12435535]

Nusbaum, HC.; Pisoni, DB.; Davis, CK. Sizing up the Hoosier mental lexicon (Progress Report No. 10). Bloomington, IN: Research Laboratory, Indiana University; 1984. p. 357-376.

Olswang, LB. Treatment efficacy research. In: Frattali, CM., editor. Measuring outcomes in speech-language pathology. New York: Thieme; 1998. p. 134-150.

Powell TW, Elbert M. Generalization following the remediation of early- and later-developing consonant clusters. Journal of Speech and Hearing Disorders. 1984; 49:211–218. [PubMed: 6716992]

Saffran JR, Thiessen ED. Pattern induction by infant language learners. Developmental Psychology. 2003; 39:484–494. [PubMed: 12760517]

Schwartz RG, Leonard LB. Do children pick and choose? An examination of phonological selection and avoidance in early lexical acquisition. Journal of Child Language. 1982; 9:319–336. [PubMed: 7119038]

Shames GH. Use of the nonsense-syllable in articulation therapy. Journal of Speech and Hearing Sciences. 1957; 22:261–263.

Shriberg LD. An intervention procedure for children with persistent /r/ errors. Language, Speech and Hearing Services in Schools. 1980; 11:102–110.

Shriberg LD. Four new speech and prosody-voice measures for genetics research and other studies in developmental phonological disorders. Journal of Speech and Hearing Research. 1993; 36:105–140. [PubMed: 8450654]

Stoel-Gammon, C. Sounds and words in early language acquisition: the relationship between lexical and phonological development. In: Paul, RPD., editor. Exploring the speech-language connection. Vol. Vol. 8. Baltimore, MD: Brooks Publishing; 1998. p. 25-52.

Stoel-Gammon C, Cooper JA. Patterns of early lexical and phonological development. Journal of Child Language. 1984; 11:247–271. [PubMed: 6746776]

Stoel-Gammon, C.; Dunn, C. Normal and disordered phonology in children. Austin, TX: Pro-Ed; 1985.

Storkel HL. Learning new words: phonotactic probability in language development. Journal of Speech, Language, and Hearing Research. 2001; 44:1321–1337.

Storkel HL. Learning new words II: phonotactic probability in verb learning. Journal of Speech, Language, and Hearing Research. 2003; 46:1312–1323.

Storkel HL. Do children acquire dense neighborhoods? An investigation of similarity neighborhoods in lexical acquisition. Applied Psycholinguistics. 2004a; 25:201–221.

Storkel HL. Methods for minimizing the confounding effects of word length in the analysis of phonotactic probability and neighborhood density. Journal of Speech, Language, and Hearing Research. 2004b; 47:1454–1468.

Storkel HL. Do children still pick and choose? The relationship between phonological knowledge and lexical acquisition beyond 50 words. Clinical Linguistics & Phonetics. 2006; 20:523–530. [PubMed: 17056482]

Storkel HL, Armbrüster J, Hogan TP. Differentiating phonotactic probability and neighborhood density in adult word learning. Journal of Speech, Language, and Hearing Research. 2006; 49:1175–1192.

Storkel HL, Morrisette ML. The lexicon and phonology: interactions in language acquisition. Language, Speech and Hearing Services in Schools. 2002; 33:24–37.

Thompson CK, McReynolds LV. *Wh* interrogative production in agrammatic aphasia: an experimental analysis of auditory-visual stimulation and direct-production treatment. Journal of Speech and Hearing Research. 1986; 29:193–206. [PubMed: 3724112]

Van Riper, C. Speech correction: Principles and methods. 4th ed. Englewood Cliffs, NJ: Prentice-Hall; 1963.

Vitevitch MS. Tongue twisters reveal neighborhood density effects in speech production. Research on Spoken Language Processing. 1997; 21:1–8.

Vitevitch MS. Influence of onset density on spoken word recognition. Journal of Experimental Psychology: Human Perception and Performance. 2002a; 28:270–278. [PubMed: 11999854]

Vitevitch MS. The influence of phonological similarity neighborhoods on speech production. Journal of Experimental Child Psychology: Learning, Memory and Cognition. 2002b; 28:735–747.

Vitevitch MS. The influence of sublexical and lexical representations on the processing of spoken words in English. Clinical Linguistics & Phonetics. 2003; 17:487–499. [PubMed: 14564833]

Vitevitch MS, Armbrüster J, Chu S. Sublexical and lexical representations in speech production: effects of phonotactic probability and onset density. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2004; 30:514–529.

Vitevitch MS, Luce PA. When words compete: levels of processing in perception of spoken words. Psychological Science. 1998; 9:325–329.

Vitevitch MS, Luce PA. Probabilistic phonotactics and neighborhood activation in spoken word recognition. Journal of Memory and Language. 1999; 40:374–408.

Vitevitch MS, Luce PA. A web-based interface to calculate phonotactic probability for words and nonwords in English. Behavior Research Methods, Instruments, and Computers. 2004; 36:481–487.

Vitevitch MS, Luce PA, Pisoni DB, Auer ET. Phonotactics, neighborhood activation, and lexical access for spoken words. Brain and Language. 1999; 68:306–311. [PubMed: 10433774]

Winitz, H. From syllable to conversation. Baltimore: University Park; 1975.

Zamuner TS, Gerken L, Hammond M. Phonotactic probabilities in young children's speech production. Journal of Child Language. 2004; 31:515–536. [PubMed: 15612388]

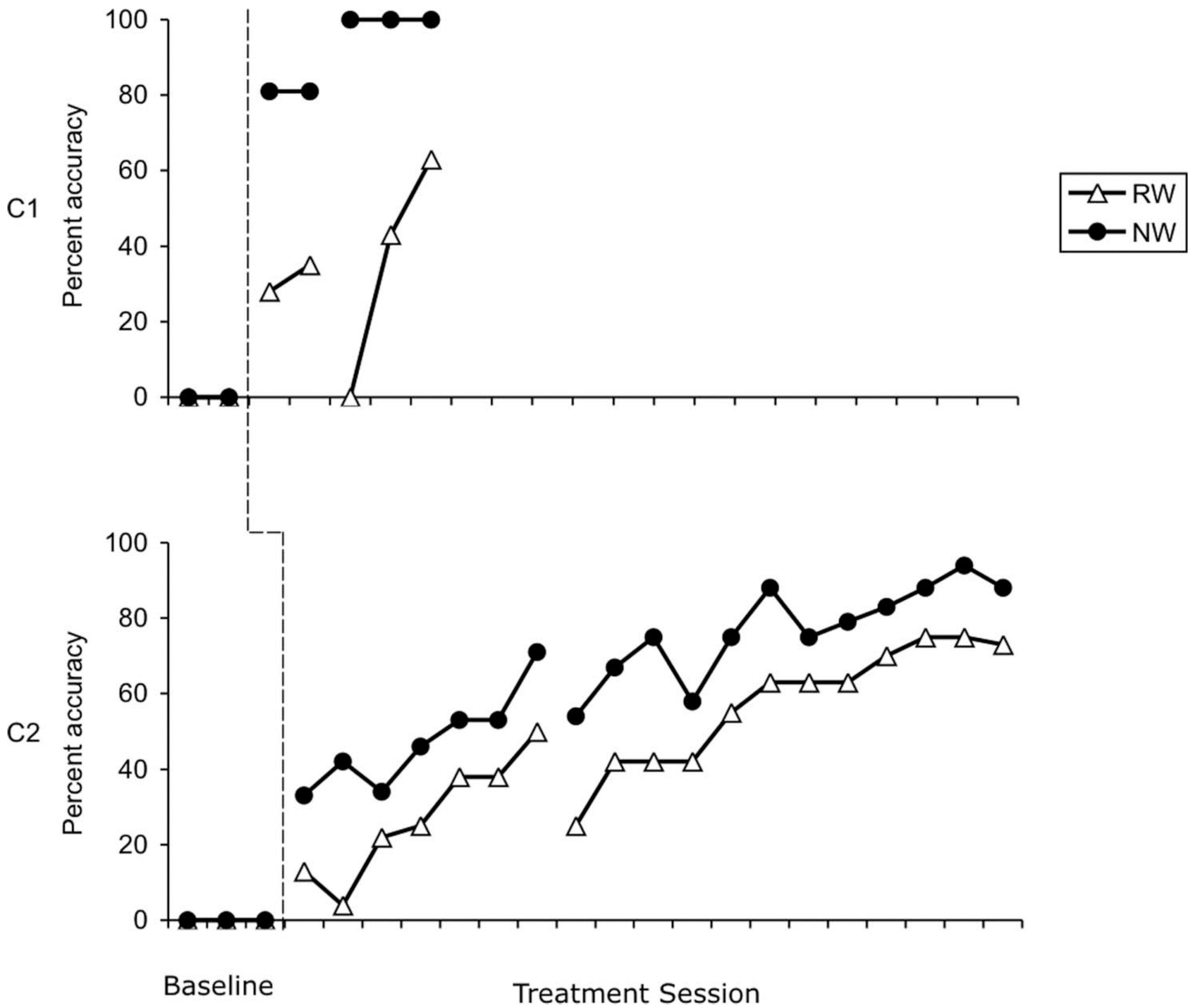

Figure 1.
Percentage accuracy of production of treated sounds in RWs and NWs for children 1 and 2. The break in the learning curves corresponds to the shift from the imitative to spontaneous phase of treatment.

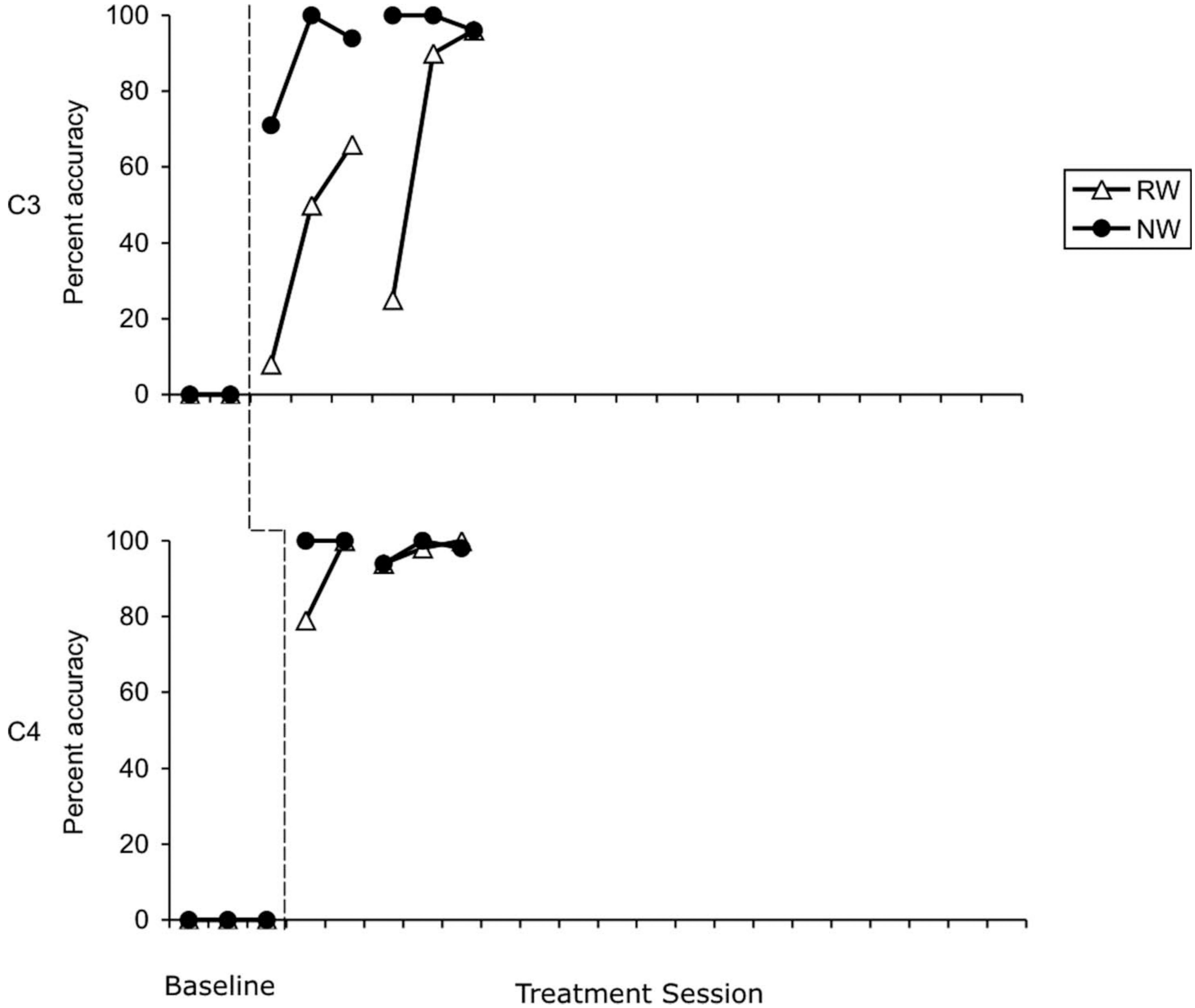

Figure 2.
Percentaeg accuracy of production of treated sounds in RWs and NWs for children 3 and 4. The break in the learning curves corresponds to the shift from the imitative to spontaneous phase of treatment.

Table I

Participants and experimental assignments.

Child	Age	Gender	GFTA-2[a]	Sounds excluded	Experimental assignment RW	Experimental assignment NW	Pre-treatment baselines
1	3;6	F	79	k ɡ θ ð z ʃ ʧ l r	1	θ	2
2	5;2	M	48	t f v θ ð s z ʃ ʧ ʤ l r h	θ	1	3
3	3;7	M	71	ŋ k ɡ θ ð sz ʃ ʧ ʤ l r j h	ɡ	θ	2
4	5;7	M	53	ŋ k ɡ v θ ð sz ʃ ʧ ʤ r	θ	ɡ	3

[a]Standard score on the *Goldman-Fristoe Test of Articulation-2* (Goldman and Fristoe, 2000).

Table II

Stimulus sets.

Treated sound	Lexicality	Treated stimuli							
/g/	RW	goon	good	gown	guess	guide	Gabby	Gary	gadget
	NW	gud	gʊm	gaʊd	gɛm	gaɪb	gæni	gɛbi	gænɛd
/θ/	RW	Thad	thick	thin	thing	thud	Thora	thorough	thighbone
	NW	θæb	θɪb	θɪm	θɪd	θʌn	θoʊmə	θʊnoʊ	θaɪdoʊd
/l/	RW	leap	lock	long	loud	line	Lenny	Lucy	leather
	NW	lim	lad	lɔm	laʊn	laɪb	lɛbi	ludi	lɛnʊb

Table III

Statistical characteristics of treated stimuli by lexicality.

	Lexicality	
Statistical characteristic	**RW**	**NW**
Sum of segment frequency[a]	−.14	−.21
Sum of biphone frequency[a]	−.09	−.37
Number of phonemes	3.44	3.47
Neighbourhood density	12.33	9.21

[a]Sum of segment frequency and sum of biphone frequency values represent *z*-score transformations to control for word length (Storkel, 2004b).

Table IV

Sample story for treated sound /g/.

RW prose	NW prose
His name is *Gary*. *Gary* has a moustache and a long beard!	His name is ɡɛ*bi*. ɡɛ*bi* has a moustache and a long beard!
The chicken’s name is *Gabby*. *Gabby* is wearing a silly hat!	The chicken’s name is ɡæ*ni*. ɡæ*ni* is wearing a silly hat!
He is wearing a wizard’s *gown*. His *gown* matches his hat!	Look, he is wearing a ɡ*a*ʊ*d*. His is wearing a ɡ*a*ʊ*d* on each hand.
He pointed and said, ‘I will *guide*’. The yellow one can *guide* them in the right direction.	They wanted to get away, so they started to ɡ*a*ɪ*b*. Look how they can ɡ*a*ɪ*b* away.
Everyone has a *gadget*. Two are yellow and one is green! Look at each wizard’s *gadget*.	Each wizard has a ɡ*æn*ɛ*d*. Two are yellow and one is green! Look at each wizard’s ɡ*æn*ɛ*d*.
He raised his hand and said, ‘Let me *guess*’. He like to raise his hand and *guess*.	He pointed to his sharp ɡɛ*m*. He has another sharp ɡɛ*m* on the other side of his mouth!
They said, ‘We will turn you into a *goon*!’ It is not nice to turn someone into a *goon*!	They started to ɡ*ud*. The stars shoot out when they start to ɡ*ud*.
They said, ‘This is not *good*’. Sitting outside in the rain and getting wet is never *good*!	They said, ‘This feels funny, it is so ɡʊ*m*’. They do not like sitting outside on the ɡʊ*m* ground!